

Sustainable management for woody crops in Mediterranean dry-lands

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Abstract

In the large inland extensions of the Spanish Mediterranean, dry-farming is predominant and the main crops are olive, vine and almond. These species represent an agricultural activity that is fundamental to the continued inhabitation of these regions. The aim of this work is to determine the chances this agriculture has of continuing by following criteria of sustainability. Having chosen goals of an economic, social and environmental nature, almost-ideal cropping plans are obtained using the Compromise Programming. Moreover, given the important role played by water availability in this type of agriculture, the study is completed by determining the impact that an irrigation-water pricing policy would have, as outlined in the European Water Framework Directive. The study leads to the conclusion that, increasing mechanization may be the most straightforward strategy to ensure the sustainability of farms in Spanish dry-lands, and specially if the current trend of increasing irrigation-water prices is consolidated.

Additional key words: compromise programming, demand functions of irrigation water, goal programming, mediterranean agro-systems, multiattribute utility theory, technological improvements.

Resumen

Sostenibilidad de los cultivos leñosos en las comarcas del secano mediterráneo

En las grandes extensiones del mediterráneo español predominan el olivo, la vid y el almendro cultivados en secano. Estas especies conforman un paisaje muy característico y, sobre todo, determinan una actividad económica que es fundamental para que estas comarcas sigan estando habitadas. El objetivo del presente trabajo es analizar las opciones de continuidad de esta agricultura, siguiendo criterios de sostenibilidad. Tras seleccionar objetivos de índole económica, social y ambiental, se obtienen planes de cultivos cercanos al ideal, a través de la Programación Compromiso. Por otra parte, y dado el importante papel de la disponibilidad de agua en esta agricultura, el estudio se completa determinando el impacto que tendría una política tarifaria en el agua de riego, como recoge la actual Directiva Marco de Aguas europea. Con los resultados se concluye que la mecanización es la estrategia más directa para asegurar la sostenibilidad de las explotaciones de las comarcas del secano mediterráneo, sobre todo si se consolida la tendencia actual de elevar los precios del agua de riego.

Palabras clave adicionales: agrosistemas mediterráneos, funciones de demanda del agua de riego, función de utilidad multiatributo, mejoras tecnológicas, programación compromiso, programación por metas.

Introduction

There are two farming systems identified with the Spanish Mediterranean lands. In littoral regions,

agriculture is irrigated, intensive and competitive, producing fruit and vegetables for fresh consumption. However, in the large inland extensions, dry-farming is predominant, and the most traditional and characteristic crops are the olive (*Olea europea* L.), the vine (*Vitis vinifera* L.) and the almond (*Prunus dulcis* Mill.) combined in different proportions on the majority of farms. The three woody species are

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grown extensively and, frequently, with marginal management. These crops are characterized by having survived the successive structural, social and economic changes that have taken place in these regions, with greater success than their herbaceous counterparts. This has helped to maintain the countryside, which is one of the marks of the cultural identity of these regions, has protected the soil from erosion, and can also be considered as an important promoter of human activity. The economic assets that are generated contribute to stabilizing the population, given that farming activities are maintained, allowing villages to remain inhabited. Moreover, even in the cases where these assets do not represent an essential proportion of family income, they do represent an important complement to the family economy.

In recent decades, socioeconomic and political changes have led to a clear transformation of the farming communities in Mediterranean inland regions. Both the industrial and service sectors continue putting strong pressure on labour resources, especially among young people, which limits generational take-over and leads to the disappearance of family farms, giving little incentive to continue farming activities.

Currently, Agenda 2000 (European Commission, 2003) urges European agriculture to be more competitive, and at the same time attributes it a determinant role in maintaining the environment. It would appear that the sustainability of most of the region is in the hands of farmers who, in their turn, find it difficult to subsist in markets that are both very open and highly competitive. The viability of this farming activity is conditioned in terms of continuity options, a term that should be understood from the economic, environmental and social viewpoints. Therefore, only sustainable planning of this activity can enable it to be maintained over time.

The present paper was conceived with the general goal of determining the possibilities of farming continuity in arid Mediterranean regions, and is structured in two parts. First of all, after reviewing the aspects that condition dry-farming in the Spanish Mediterranean regions, cropping plans will be studied from a sustainable perspective, applying compromise programming (Yu, 1973; Zeleny, 1973). The analysis will be carried out in two productive scenarios, which are also to be found in real life. While the first, with scarcely mechanized farms, is the most widespread, the second corresponds to farms with an important increase

in the degree of mechanization of the crops, which are still a minority in the study areas. Given the incidence of the price and availability of irrigation water in these farms, the study is concluded by applying the multiattribute utility theory (Keeney and Raiffa, 1976) and determining the demand functions of water with those that evaluate the impact that a policy of increased irrigation-water prices would have on this agriculture if applied. To improve the understanding of this work, the principles of the two methodologies and the application of these are described in two different sections.

Sustainability of Mediterranean dry-farming

The concept of sustainable agriculture encompasses three fundamental objectives: profitability, social equity and conservation of natural resources (Jiménez and Lamo de Espinosa, 1998). In fact, an agricultural farm does not look exclusively for economic profit, but instead the farmers' decision-making process is guided by several objectives, as shown in the work by Gasson (1973) or Costa and Rehman (1999). The value of the different multicriteria techniques for this analysis has been widely described in the scientific literature and, according to Masera and López-Ridaura (2000) they are considered to be the best procedures with which to analyse the sustainability of the agrarian system.

In the analysis of the sustainability of a region or a farming activity, there are many studies that integrate the economic parameters with others of an agro-ecological or technological nature, such as that of Tellarini and Caporali (2000) or Darwish *et al.* (2001) and in others, mathematical programming is applied, like in Ruben and Ruijven (2001), Belcher *et al.* (2004) or in Fernández-Zamudio *et al.* (2005). In fact, mathematical programming is the tool used to analyse sustainability in the present work.

The most outstanding traits of the dry regions and the choice of objectives to introduce in the models

The present study focuses on the *Comunidad Valenciana* (Valencian community). Although internationally known for its fruit and vegetables, which are mainly grown in the irrigated coastlands, the

dry-lands account for 56% of this region, and together the olive, vineyard and almond are the most extensive crops, representing 35% of the worked lands in this region. These crops make a decisive contribution in these inland regions, which have the lowest prospects of development in the industrial and service sectors.

Three objectives have been chosen to analyze the sustainability of this agriculture, one of an economic nature, another social one and the other environmental.

From the economic point of view, the priority on all the farms is to maximize profits. In this study, the net margin is taken, and then with the income the variable costs are deduced as well as the fixed costs, among which the depreciation of the plantation is included.

On the other hand, the social circumstances lived in these areas must be taken into account. In many of these regions, the agricultural labour workforce is comprised by elderly men, who lengthen their working life in the absence of a generational take-over and agriculture is frequently part-time. Therefore, as a social objective we have chosen the minimization of the total annual workforce. In this sense, technological improvements can help the viability of traditional agriculture. For example, harvest mechanisation not only reduces labour and production costs considerably, but also facilitates crop management by eliminating the main peak in manual labour. Given the advantages this machinery represents, it can be either owned or hired.

The size of the farm also exerts an influence. In contrast to the small-holding structure characteristic on the coast, in these inland regions the land is not considered as such a restrictive factor, and usually, the lack of family labour needed to cultivate the farm in optimum conditions leads to marginal management. Marginal management is a non-definitive, semi-abandonment, in which these three tree crops survive, left to the mercy of the climate. This is often the case in the regions under study and at specific periods of time when, due to the lack of labour or profitability, the farmers do not optimize crop care and limit it to a minimum.

Together with the land, the other most important natural resource is water, which is in short supply and highly valued, given that, in the arid regions of the Mediterranean, agriculture is strongly conditioned by the irregularity of the climate, specially the rains. Although in the dry-farmed regions of the Mediterranean it is possible to find a certain proportion of the farmed area with some type of irrigation system, a farming system that contemplates a large-scale

transformation towards irrigation cannot be considered as viable. The existing subterranean water levels in the region under study are already at the limits of exploitation, and irrigation capacity is limited to occasional and small watering.

Crop planning from a sustainable point of view

Information and methodology

Family farms predominate in the Mediterranean inland regions, and the analysis was carried out on a representative farm, with 32 hectares of land and a full-time family Agricultural Work Unit (AWU). To establish the technological itineraries, data were collected through 45 questionnaires completed by farmers considered characteristic of the region. Afterwards, the data were reviewed with experts enabling us to establish technical coefficients, considered as representative of this whole area and that encompass the inter-annual variability depending on the weather.

Within the *Comunidad Valenciana*, the study was located in the l'Alcoià area. This is a region with a semi-arid climate, with the risk of frost from November to March, and 474 mm of average rainfall per year. In this region, there are two zones with very different slope characteristics, but with a moderate risk of natural erosion. The irrigation water mainly comes from private wells, and a small proportion is distributed by the Irrigation Society (*Comunidades de Regantes*) of the River Vinalopó.

Quantitative analysis has been carried out using the Compromise Programming (CP), technique belonging to the multicriteria paradigm. The objectives included in this analysis are: maximization of the net margin of the farm, minimization of irrigation water consumption and minimization of the total labour employed. The mathematical expression of these three objectives is:

$$\text{Max} \sum_{i=1}^n NM_i \cdot X_i$$

$$\text{Min} \sum_{i=1}^n Q_i \cdot X_i$$

$$\text{Min} \sum_{i=1}^n TL_i \cdot X_i$$

Where NM_i is the net margin of the activity i , X_i is the surface area, Q_i is the annual irrigation water supplied and TL_i is total labour employed annually.

As will be seen later, the previously mentioned objectives will conflict with each other, making it impossible to optimize the three objectives simultaneously and achieve an ideal solution. However, it is possible to determine the small group of effective points that bring us closest to that ideal, which would be the solution in which all the objectives reach their optimum value (Romero and Rehman, 2003). The mathematical essence of this calculation was established by Zeleny (1973) and Yu (1973), and a number of authors have used this technique in agriculture. For example, Sabuni and Bakshoudeh (2004) used the CP to determine the opportunity cost of water on farms; Ballestero *et al.* (2002) to analyse establishing water markets, and in Raju *et al.* (2000) and Manoliadis (2001), CP is a tool to evaluate the sustainability of different arable areas.

The CP is one of the most commonly applied multicriteria techniques due to its high operativity (Romero and Rehman, 2003). It is associated with the concept of distance, although not in a geometric sense, but rather the distance or degree of proximity from the ideal. This distance (d_j) of the objective $f_j(x)$ with respect to the ideal f_j^* , will be written:

$$d_j = |f_j^* - f_j(x)|$$

Normally, the objectives have very different absolute values or are measured in different units. Therefore, before adding their possible degrees of proximity, one must carry out a dimensional homogenization, giving:

$$d_j = \frac{|f_j^* - f_j(x)|}{|f_j^* - f_{*j}|}$$

where f_{*j} is the worst value of the objective when it has been optimized separately and called the anti-ideal value.

Likewise, in the calculation one must also consider the preferences that the decision centre can show for each objective, represented by the weight w_j . All this means that the effective solutions that come closest to the ideal are achieved by resolving the following optimization problem:

$$\text{Min } L_p = \left[\sum_{j=1}^n w_j^p \cdot \left| \frac{f_j^* - f_j(x)}{f_j^* - f_{*j}} \right|^p \right]^{1/p}$$

Subject to $x \in F$, where x are the decision variables, F is the set of restrictions of the model, n is the number of the objectives introduced in the modelization and p the metric (Romero and Rehman, 2003).

The points that fall closest to the ideal (called the compromise set) can be bounded between the metrics one and infinity, in other words L_1 and L_∞ (Yu, 1973), which is considered acceptable, even though there are more than two objectives. The economic significance of these solutions is associated with the traditional optimization based on utility functions and L_1 indicates the value of greatest efficiency, while L_∞ is the solution with the greatest equity (Ballestero and Romero, 1991).

Establishing the mathematical models

The calculations were applied to two real modelled scenarios in these regions, and the differences observed were exclusively in the degree of mechanization existing on the farm. In the «manual-scenario» low-powered mobile equipment was used together with traditional harvesting and hand-picking, and in the «mechanized-scenario» higher-powered mobile equipment was considered, together with the use of pre-pruners and harvesting with integral grape-collectors in the vines, and automatic vibrators with mechanized picking and fruit loading systems in the olives and the almonds. All these improvements enabled the amount of labour to be reduced, thus lowering costs.

In this study, the decision variables, or unknowns of optimization, correspond to the surface area in exploitation for each crop-growing activity. Olive, vine and almond, which are the most characteristic crops in the region, have been introduced, the main difference being the amount of irrigation (Table 1). These three crops can be cultivated in strict dry-farming or with irrigation at very specific moments (irrigated relief), considered as essential to ensure harvest. Also, in the case of the vineyard and olive conventional drip irrigation is also possible, with greater and more continuous flow. Irrigation is always applied by a drip system.

Table 1. Decisional variables: description, net margin for scenarios and annual water supply

Species	Varieties, description	Irrigation	Decisional Variable	Annual water supply (m ³ ha ⁻¹)	Net margin Manual-scenario (€ ha ⁻¹)	Net margin Mechanized-scenario (€ ha ⁻¹)
Olive	Authochthonous: Grossal	Dry land	OGD	0	315	314
Olive	Authochthonous: Grossal	Irrigated relief	OGIr	700	662	734
Olive	Authochthonous: Grossal	Irrigated	OGI	1,500	1,314	1,511
Olive	New: Arbequina	Dry land	OAD	0	441	300
Olive	New: Arbequina	Irrigated relief	OAIr	700	933	858
Olive	New: Arbequina	Irrigated	OAI	1,500	1,585	1,611
Almond	Authochthonous: Comuna Group	Dry land	ACD	0	236	330
Almond	Authochthonous: Comuna Group	Irrigated relief	ACIr	700	151	329
Almond	New: var.Late-flowering	Dry land	ALD	0	451	577
Almond	New: var.Late-flowering	Irrigated relief	ALIr	700	360	568
Vine	Monastell in tube	Dry land	VTuD	0	550	564
Vine	Monastell in tube	Irrigated relief	VTuIr	1,100	783	807
Vine	Monastell in tube	Irrigated	VTuI	1,900	1,458	1,492
Vine	Monastell in espalier	Dry land	VED	0	499	655
Vine	Monastell in espalier	Irrigated relief	VEIr	1,100	788	955
Vine	Monastell in espalier	Irrigated	VEI	1,900	1,409	1,602

Source: own calculations.

To bring the models closer to the real conditions in the region, a number of restrictions have been taken into account, and have been introduced equally in both scenarios:

— Crop area: A total of 32 hectares are available on the farm.

— At maximum, 30% of the available surface area can be subject to marginal management, a concept already defined above.

— Given that these are woody crops, and that the models under consideration are static and short-term, the maximum surface area of each species is limited to its present value (32% in olive, 8% in almond and 60% in vine). This restriction permits changes in variety within a species, changes in the type of irrigation, or for this to change to marginal management.

— Due to the dryness of these regions, very strict irrigation conditions are established. Water use is usually fixed at a level equivalent to the standard levels of consumption, and, according to the criteria of the experts consulted, can be maintained medium term (Table 1). It has, therefore, been established that only 10% of the available surface area can receive some kind of irrigation, the water supplied cannot exceed 600 m³ monthly for the whole farm, and the total amount

allotted to the farm is 5,000 m³ annually. The current price of irrigation water is 0.15 € m⁻³.

— Other restrictions are derived from manual labour. The availability of family labour is fixed at one agricultural work unit (an AWU corresponds to 2,160 hours a year), and hired labour is limited to complement what cannot be covered by a family on a three-monthly basis.

To calculate the net margin of an activity, the variable costs (including hired labour) and the fixed costs are subtracted from the income earned by selling the production (together with the subsidy if there is one) (Table 1). To calculate the income, the average production for each crop-growing activity was fixed according to the data recorded in the region and after validating these data with experts. In the production figures considered, inter-annual variability in yield is recorded. Alternate bearing in the olive has been taken into account and, in the case of the almond, the probability that every 6 or 7 years there is zero harvest, due to the risk of frost. For the newly introduced varieties in this region ('Arbequina' olive and the late-flowering almond) the average harvest has been estimated according to related bibliography and the opinion of experts. For the prices, average values have

been taken as those perceived by the farmers, according to official statistics (Generalitat Valenciana, 2005), giving an average for a five year period and updating the value in June 2005.

To bestow equal prospects on all the farm owners, independently of the capital at their disposal to mechanize their holding and to be able to adopt a mechanized scenario, the most expensive machinery required is hired. Therefore, all depreciation costs for the small machinery are introduced (as this tends to be owned by the farmer), and the hiring cost in the case of larger machinery, such as harvesters and vibrators.

Crop planning: results and discussion

After optimizing the objectives separately a pay-off matrix is obtained for both scenarios (Table 2). A high degree of conflict is evident between the three objectives, given the differences between the ideal and anti-ideal values, while important improvements can be foreseen if the mechanized scenario is adopted.

Continuously, the three initially proposed objectives have been integrated, with equal weight, and the compromise set has been calculated in both scenarios. Therefore, with the analysis of these two scenarios, it is possible to evaluate the repercussions derived from implanting these technological improvements, and the impact these could have on the sustainability of agricultural activity.

Table 3 shows the achievement levels for each of the three objectives for the metrics L_1 and L_∞ , the different cropping plans and the requirements of hired manual labour.

The results show a number of advantages on moving from the manual scenario to the mechanized scenario, which can be defined as follows:

— With the proposed improvements, there is an increase in the average profit per cultivated hectare and the values reached indicate that the economic viability seems to be guaranteed in the medium term. On mechanization, in particular, net margin values are achieved of between 559 and 588 euros per cultivated hectare, although the calculation was made by assigning the same weight to the three objectives. If maximization of the net margin is considered to have greater weight than the other two objectives, the cropping plans obtained would give even better economic results.

— Water requirements in the most balanced cropping plan (L_∞ , which is the one that demands most irrigation, do not exceed 2,227 m³ a year on the whole farm in the manual scenario, and 2,418 m³ for the mechanized scenario. Given the strict conditions used to develop the models, the proposed plans could possibly be sustainable, even in these arid agricultural conditions. Moreover, in solution L_1 there are plans that do not require irrigation, verifying the continuity of traditional dry-farming on its own.

— The most outstanding difference is obtained for the objective concerning the total labour. If the two most efficient cropping plans are compared (metrics L_1), the manual scenario requires 2,014 working hours a year and only 1,200 hours are required in the mechanized one, a reduction in manual work of 40%. If the two most efficient solutions are compared (metrics L_∞), this reduction exceeds 43%.

— While in the manual scenario one needs to contract 631 hours a year in one case and 1,052 hours in the other, in the mechanized scenario a maximum of 106 hours of hired work are required per year, which reduces the costs and, above all, allows greater independence, a strong motivation among land-owners in the region.

Table 2. Pay-off matrix for the three objectives analysed for compromise solutions. Data for a family farm with an agricultural work unit and 32 ha

Objectives	Manual-scenario			Mechanized-scenario		
	NM	Q	TL	NM	Q	TL
NM, net margin (€)	19,891	16,230	9,110	21,419	17,268	10,107
Q, annual irrigation water (m ³)	4,800	0	0	4,800	0	0
TL, total labour employed annually (h)	3,476	3,022	1,940	1,987	1,766	1,008

Source: own calculations.

Table 3. Cropping plan and results for the three objectives analysed for compromise solutions (Data for a family farm with an agricultural work unit and 32 hectares)

Metrics ¹	Manual-scenario		Mechanized-scenario	
	L ₁	L _∞	L ₁	L _∞
<i>Value of objectives:</i>				
— NM, net margin (€)	10,950	14,889	12,520	16,241
— Q, water (m ³)	0	2,227	0	2,418
— TL, total manual labour (hours)	2,014	2,653	1,200	1,505
<i>Optimisation activities (%):</i>				
— OGD: Olive. Grossal. Dry land			2	13.3
— OAD: Olive. Arbequina. Dry land	32	27.4		
— OAI: Olive. Arbequina. Irrigated		4.6		5
— ATD: Almond. Var.Later flowering. Dry land	8	8	8	8
— VTuD: Vine. Tube. Dry land	30	42.7	60	60
— Marg.: Farm surface with marginal management	30	17.3	30	13.7
Total hectares properly cultivated (ha)	22.4	26.5	22.4	27.6
Net margin (euros per cultivated hectare)	489	562	559	588
Annual requirement of hired manual labour (hours)	631	1,052	0	106

¹ Metrics L₁ indicate the value of greatest efficiency, and L_∞ the solution with greatest equity, they determined compromise set.
Source: own calculations.

— Mechanized harvesting also favours farm management and reduces the percentage of land with marginal management, which takes up at least 17.3% of the estate in the manual scenario, but can represent only 13.7% in the mechanized one. Given that some of the consequences of marginal management are a decrease in soil fertility; a loss in the crops' productive potential; or the danger of them developing pests and disease, one can consider that mechanization reinforces the global sustainability of the farm.

— Other consequences of adopting improvements in the mechanized scenario are the introduction of autochthonous varieties, such as the olive 'Grossal', which is not reflected in the solutions in the manual scenario. The cropping plan to predominate after adopting technological innovations would undergo an important increase in the vine, a species that is greatly favoured as it requires pre-pruning and mechanized harvesting.

Having reached this point, it is especially interesting to reflect on the behaviour of the profit maximization objective with respect to minimizing irrigation water. If the compromise sets are calculated just for these two objectives, these points can be represented on a Cartesian plane and, the slope of the line joining the points L₁ and L_∞, or trade-off, show us the opportunity

cost or the shadow price of the irrigation water, understood in its marginal values, in other words, as the increase in the net margin of the farm if one applies an additional unit of water (Florencio-Cruz *et al.*, 2002).

The lines obtained in both scenarios are represented in Figure 1. The volume of irrigation water required by such a plan is represented on the abscissa axis, while the ordinate axis shows the net margin this plan generates. The result is a shadow price of water of 0.76 € m⁻³ in the manual scenario and of 0.87 € m⁻³ in the mechanized ones. The highest shadow price obtained in both scenarios is very significant, and they give a useful estimation of the value of water in this dry-farming system. However, they have been obtained by exclusively evaluating the impact of irrigation water on the net margin of the farm. To obtain more rigorous information about how these crops would behave in the event of an increase in water prices, the demand curves will be calculated in the following section.

Analysis of the impact of a pricing policy for irrigation water on dry regions

On approving the Water Framework Directive, the European Parliament sets out a number of actions

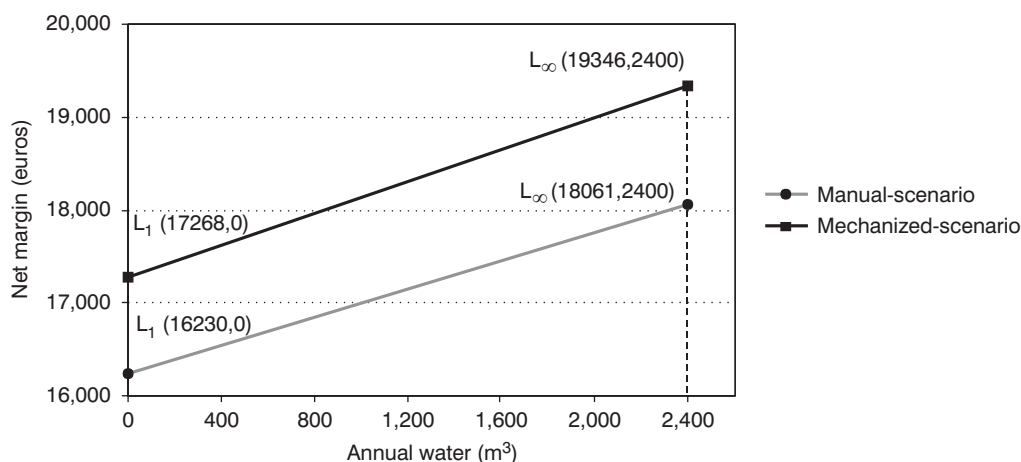


Figure 1. Shadow price of irrigation water for two scenarios (Data for a family farm with an agricultural work unit and 32 hectares).

regarding water policy at the Community level (OJ, 2000). This Directive, with a clear environmental focus, established the convenience of using pricing as an economic tool to increase the efficient use of water resources, proposing the achievement of full-cost recovery of water by 2010. It seems difficult to find a method with which to achieve this objective directly, but an approximation can be made of the expected response in the event of applying a water-pricing policy using the neoclassical economic theory, and more recently the multiattribute utility theory (MAUT). As in the present paper, previous works, like those by Berbel and Gómez-Limón (2000) or Gómez-Limón and Riesgo (2004) point out the suitability of the MAUT to obtain demand functions.

Methodology applied to obtain the demand functions for water

The work by Keeney and Raiffa (1976) is a starting point of the MAUT. It essentially consists of being able to establish a mathematical function U , which encompasses the utility resulting from a series of attributes, which are previously considered according to the importance of each one for the decisor. This theory starts from strict mathematical requirements. However, the works by Edwards (1977), Farmer (1987) or Huirne and Hardaker (1998) show that, although these are not wholly satisfied, one can obtain utility functions that are extremely close to the true utility.

In order to estimate the additive utility functions, the framework developed by Sumpsi *et al.* (1996) and Amador *et al.* (1998) has been followed, and later applied by Gómez-Limón *et al.* (2004). First, one calculates the pay-off matrix, and then resolves the following system of $n+1$ equations:

$$\sum_{i=1}^n w_i f_{ji} = f_j$$

for $j = 1, 2, \dots, n$ and $\sum_{i=1}^n w_i = 1$.

With n being the number of objectives considered, w_i are the weights of the different objectives (and therefore, unknown), f_{ji} are the elements of the payoff matrix, corresponding to the values reached by the objective of column- i when the objective of row- j is optimized. Finally f_j is the value of the j -th objective in accordance with the distribution of the crops observed.

If the above system of equations has a non-negative solution, then w_i indicates the weights of the different objectives, but this is not usually the case, as there is no set of weights that reproduce the farmers' preferences with precision. To approximate the said solution as far as possible, one minimizes the sum of n_j and p_j , for which the following lineal program is resolved:

$$\text{Min} \sum_{j=1}^n \frac{n_j + p_j}{f_j}$$

subject to:

$$\sum_{i=1}^n w_i f_{ji} + n_j - p_j = f_j \text{ for } j=1, 2, \dots, n$$

$$\sum_{i=1}^n w_i = 1$$

with n_j corresponding to the variable of negative deviation and p_j the variable of positive deviation.

According to Dyer (1977), the weights obtained previously, coincide with the following expression of the utility function, which is separable, additive and lineal for each attribute, $f_i(x)$,

$$U = \sum_{i=1}^n \frac{w_i}{k_i} f_i(x)$$

where k_i is a normalizing factor, for instance the difference between the best or ideal value for each objective, f_i^* , and the worst or anti-ideal, f_i^* , which are extracted from the pay-off matrix, with the additive utility function finally being expressed as:

$$U = \sum_{i=1}^n w_i \frac{f_i(x) - f_i^*}{f_i^* - f_i^*}$$

The utility function has been found that is characteristic of a farm like the one described in the first part of this paper, which in turn is representative of the region under study. It has been assumed that farm owners will maintain their psychological attitude with regard to decision taking for a short to medium term. The study then goes on to look at a series of simulations with rising prices of irrigation water, such that each price is a new scenario in which utility is maximized, and from which a cropping plan is derived with a specific demand for irrigation water.

The curves obtained will be a consequence of the adaptation of the farm in the short-term to increasing prices of irrigation water. The simulation models are applied to the manual scenario and to the mechanized scenario and are similar to those used in the first part of this study, with the following considerations:

— The MAUT is obtained for the objectives: maximization of the net margin of the farm and minimization of total workforce.

— From the previously calculated margin (Table 1), the cost of the water (corresponding to the usual price, 0.15 € m⁻³) is deducted and the value corresponding to each simulation, starting from 0 € m⁻³, is added.

— Restrictions to the models, and the average volumes of irrigation applied to each variety of crop coincides with those described previously (Table 1).

Demand functions: results and discussion

The demand curves obtained are shown in Figure 2. In the event of applying a hypothetical pricing policy, a farm's behaviour will vary according to its degree of mechanization, although we observe that water consumption in the lowest price range is equal in both scenarios. This highlights an inelastic behaviour of the different price ranges, and undoubtedly the great shortage of this resource in these regions and the high productivity of water, even in small amounts, mean that the price the farm can pay for irrigation water can be increased.

In the manual scenario, there is a first range of maximum demand, between 0 and 0.51 € m⁻³; this continues with a drop to half the demand for tariffs of 0.52 to 0.55 € m⁻³ and ends up with cropping plans in completely dry-farming when the water costs over 0.56 € m⁻³. In the mechanized scenario, the demand is constantly at a maximum until it reaches 0.91 € m⁻³, at which point the chosen cropping plan changes to one that is strictly dry-farming. The different response must be looked for in the different degrees of mechanization. Technology improves management and enables farms to face the greater labour requirements that arise from irrigated crops more effectively. This limitation is accentuated if the labour (especially harvesting) is carried out manually, and for this reason mechanized farms are more able to pay higher water prices.

The maximum annual water allotment, which was fixed at 5,000 m³, is not reached in either scenario. Through sensitivity analysis one can detect that the limitation comes about through a monthly restriction (of 600 m³), especially for the greater demand in the summer months. If the farm has a small reservoir this would somewhat increase the monthly supply and could modify the cropping plan chosen initially.

The price of water has repercussions on the cropping plan resulting from each simulation. When the prices are low, water is demanded for irrigation and this is

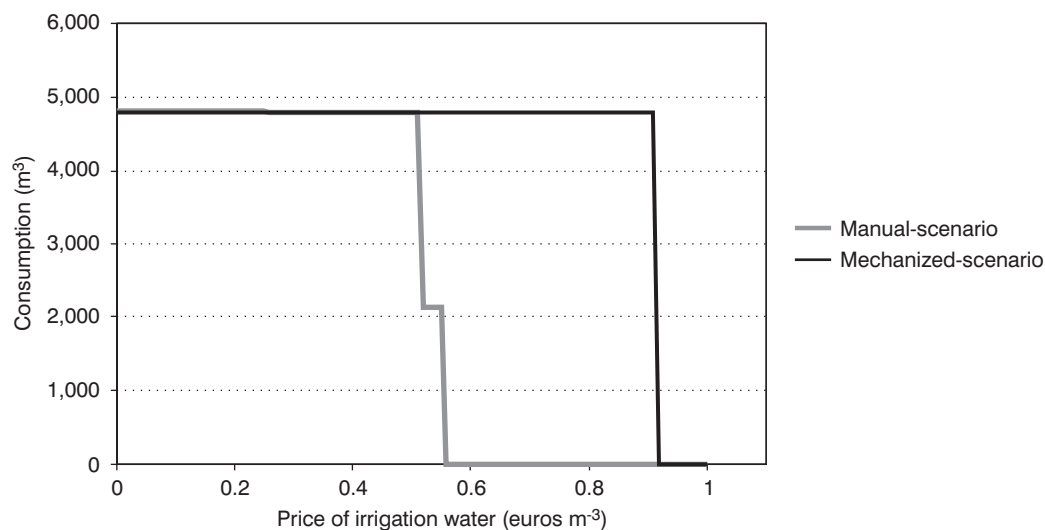


Figure 2. Demand functions for irrigation water for the two scenarios.

destined solely to the olive, specifically to the OAI (olive Arbequina irrigated) activity. However, for both the almond and the vineyard dry-farming is always chosen. In the manual scenario, the dry farmed olive is the Arbequina, while in the mechanized scenario is the autochthonous variety Grossal. With respect to the vine, in the manual scenario it is trained in tube, while in the mechanized one it is trained in espalier (which is more productive but requires a greater initial investment). The almond chosen is a late-flowering variety in both scenarios. The cropping plans in the mechanized scenario are more economically viable, which means that, with prices of over 0.51 euros m⁻³, they can demand greater quantities of water than in the manual one.

Each cropping plan generates a net margin on the farm, some labour requirements, and water consumption. Another indicator is the surface area of land necessary to achieve a minimum income, for example 21,500 euros. All these indicators help to understand the economic, social and environmental repercussions of a hypothetical irrigation water pricing policy in these regions. Figures 3 and 4 show the variation in the same for six price levels that are higher than the current ones, taking into account that the usual cost of irrigation water in this region is 0.15 euros m⁻³.

In the manual scenario (Figure 3), in line with the increase in water prices there is a decrease in the income, the water consumption and the manual labour

demand by the chosen crops. The farm could be unviable if water price exceeds 0.24 € m⁻³, and over 0.51 € m⁻³ a totally dry cropping plan is adopted. Without irrigation, the net margin of the farm is 18,810 €, employing an average of 100 hours manual work annually per cultivated hectare. At the present price of water, the minimum income is obtained by cultivating 31.3 ha, but 36.6 ha are needed if cultivation is totally dry.

Figure 4 shows the effects on a farm in the mechanized scenario. The reference income is not assured if the price of the water is over 0.44 € m⁻³, and if the price of irrigation water exceeds 0.91 € m⁻³, it converts to dry cultivation. With the present price of water, the minimum income is obtained by cultivating 30 ha, but in the case of strict dry cultivation 37 ha are necessary. The high stability in manual-work requirements is notable, which is practically 80 h ha⁻¹ annually for all water prices.

Conclusions

In order to establish a sustainable plan for agriculture, one must use strategies that help to boost economic development, improve life quality in the rural societies and mitigate the negative effects by using their main natural resources. In the specific case of arid Mediterranean regions, some of these strategies

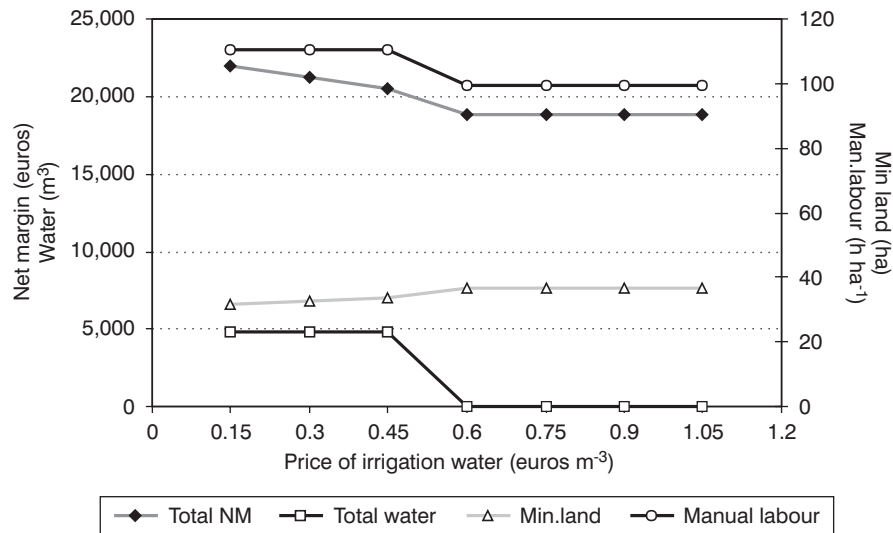


Figure 3. Repercussions derived from the application of a water pricing policy (manual-scenario).

are pin pointed using multicriteria tools, with which cropping plans are determined, integrating objectives of a very different nature.

The analysis has been carried out at the level of a farm, but the type of farm to be chosen is very widespread in the Mediterranean regions of the Spanish dry-lands, and both the technical coefficients as well as the restrictions introduced in the models, cover the

productive characteristics for a large part of this territory.

In the first part of this article, some sustainable cropping plans are obtained through the Compromise Programming, given that they are close to the ideal of these three objectives: to maximize the net margin, minimize water consumption and minimize total labour. In the analysis, the increase in the degree of

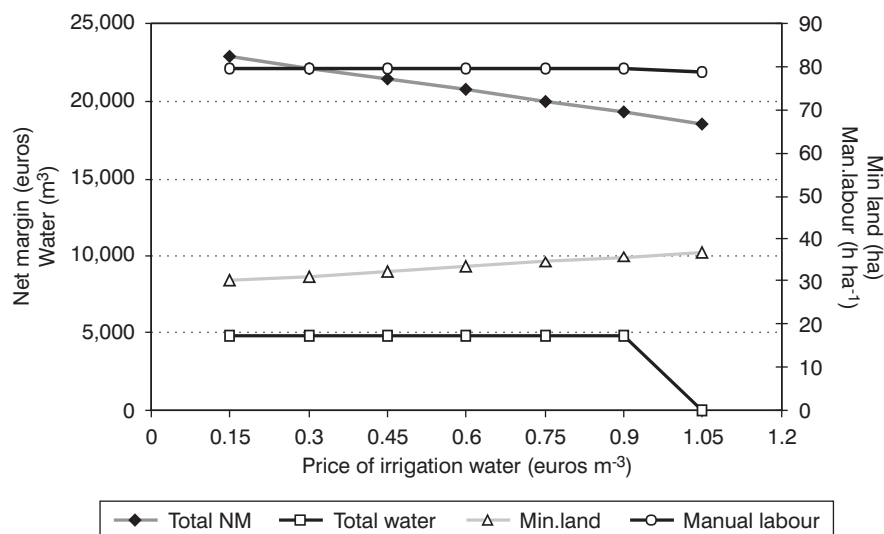


Figure 4. Repercussions derived from the application of a water pricing policy (mecanized-scenario).

mechanization has been evaluated, specifically the use of tractors and more powerful equipment is proposed, like pre-pruners in the vine and mechanized harvesting in all of the crops. The repercussions of increasing mechanization are:

— To improve the economic results of the farm (net margin per cultivated hectare) and to considerably reduce the total labour required annually, as well as the need to contract casual labour, giving greater independence to the family business.

— To optimize management, allowing a smaller surface area to be subject to marginal management, representing the part of the farm that is more susceptible to reduced fertility, does not generate profits and suffers from more pest outbreaks etc. These agronomic and environmental drawbacks must, therefore, be minimized.

— Autochthonous varieties may be more viable, at least in the olive, which increases biodiversity and enhances the continuity of traditional genetic wealth.

— With respect to the use of water, which is the natural resource of greatest scarcity and highest value in these regions, in the two scenarios total dry-farming cropping plans have been chosen (metric L_1), which tells us about the sustainability of traditional dry-farming. Despite this, other plans can be economically more profitable (metric L_∞) using very small amounts of water (between 2,227 and 2,418 m³ annually for the total farm) and therefore medium term variables are also considered.

Next, a first approximation will be made of the value of irrigation water on these farms, which will be done graphically, representing the compromise sets of net margin maximization and the minimization of water on a Cartesian plane (Figure 1). The high shadow prices obtained (0.76 € m⁻³ in the manual scenario and the 0.87 € m⁻³ in the mechanized one) raised the need to value the maximum price that the farm could afford.

Finally, we obtained the demand functions by applying the Multiattribute Utility Theory, a technique that can be used to make simulations and to study the impact of a hypothetical pricing policy, like that proposed in the European Water Framework Directive. The curves lead us to the following conclusions:

— The different sections of the demand curves demonstrate very inelastic behaviour, which is justified

by the fact that the olive, vine and almond are woody species that use small amounts of irrigation water very effectively.

— The effect of the price of water on the farm's income make a higher degree of mechanization necessary in order to face the high irrigation-water prices. The current price of water is 0.15 € m⁻³, and although it could increase, to ensure a minimum income for the farm of 21,500 € annually, water cannot exceed more than 0.24 € m⁻³ in a manually worked farm, or more than 0.44 € m⁻³ if it is mechanized.

Therefore, to increase mechanization may be the most straightforward strategy to ensure the survival of farms in the Spanish dry-lands, in the short to medium-term, and likewise to enhance their sustainability. As all the results have been obtained considering that operations demanding the most expensive machinery are hired, this strategy can be assumed by all the farms. It will, therefore, be essential to increase the degree of mechanization in order to guarantee the viability of this agriculture if the current trend of increasing irrigation-water prices is consolidated.

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